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Designing of DSTATCOM for Enhancing Power Quality using Indirect Current Control Theory with the help of PI & Hysteresis Controllers

Virendra Jain[1], C. Veeresh[2] and Virendra S. Solanki[3]

[1,2,3]Deptt. of Electrical & Electronics Engg. MIT Mandsaur-458001 (M.P.), India
E-mail: [1]er.virendrajain@gmail.com, [2]c.veeresh@mitmandsaur.info, [3]virendra.s.solanki@gmail.com

Abstract: *This work presents a method capable of designing DSTATCOM to reduce harmonic distortion and correct the power factor to improve power quality. The DSTATCOM with Indirect control Theory feeds a wide variety of loads. The performance of the system is simulated for linear, non-linear load. Simulation results justify enhanced power quality of the system with DSTATCOM application.*

Keywords: - *Programmable Source, DSATACOM, Capacitive filter, Power Quality, PI & Hysteresis controller.*

1. INTRODUCTION

The Distribution Static synchronous Compensator (DSTATCOM) is a main member of the FACTS family of power electronic based controllers. It has been studied for many years, and is probably the most widely used FACTS device in today's power systems. The DSTATCOM voltage and reactive power compensation are usually related through the magnetics of the DSTATCOM. This traditional power flow model of the DSTATCOM neglects the impact of the high frequency effects and the switching characteristics of the power electronics on the active power losses and the reactive power injection (absorption).

The D-STATCOM has emerged as a hopeful device to offer not only for voltage sag reduction but also for a host of other power quality solutions such as voltage stabilization, flicker suppression, power factor correction, and harmonic control. D-STATCOM is a shunt device that produces a balanced 3-ϕ voltage or current with capability to control the magnitude and the phase angle. Generally, the D-STATCOM configuration consists of a typical 12-pulse inverter arrangement, a dc energy storage device; a coupling transformer linked in shunt with ac system, and connected control circuits. The configurations that are additional cultured use multi pulse and/or multilevel configurations. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. By controlling the firing angles of VSC, the reactive power can be generated from or absorbed by STATCOM and the voltage regulation can be accomplished.

The simulation results show the improvement in current control response. These methods are tested in MATLAB, and their results are obtained.

2. SYSTEM CONFIGURATION

A Distribution static compensator (STATCOM) is electronic based devices which improve power quality in electrical distribution system. It is based on a power electronics voltage source converter and can act as either a source or sink of reactive AC power to an electricity network in fig .1 shows an isolated distribution system with DSTATCOM installed on it. A programmable voltage source is applied in the system. DSTATCOM in shunt configuration act as a source of leading or lagging vars s applied to regulate the voltage at the point of common coupling (PCC). When the load of end-user is less than the constant power generated by the non-liner load, the additional power absorbed by DSTATCOM whereas when the load is exceeds the requirement of end users of nonlinear load capability, DSTATCOM also acts as a source of power. DSTATCOM provides the needful reactive components of the supply current and also maintaining voltage at PCC terminals as well as harmonics compensation. Fig. 1 shows the block diagram of system with DSTATCOM.

3. CONTROL SCHEME

The configuration of DSTATCOM as shown in Fig. 1 consists of the DC link; hence the DC link voltage remains practically constant. A DC link capacitor (C1) is also connected as shown. The values of the parameters for capacitor and controller are mentioned in Parameter list. The block diagram for the control scheme of DSTATCOM is shown in Fig. 2. It utilizes one proportional-integral (PI) controller for regulating the ac terminal voltage. The In-phase components of the DSTATCOM reference currents are required for charging the dc capacitor to the level of reference dc bus voltage and to meet its losses. The amplitude of in-phase component of the reference supply currents (I_{spdr}) is kept constant at a particular value depending on actual power necessary of the load. The instantaneous values for in-phase components of supply reference currents are obtained by multiplying I_{spdr} with the in-phase unit current vectors (u_a, u_b, u_c) derived from three phase sensed terminal voltages ne PI controller is applied over the sensed and reference ac mains voltage. Its output is considered as the amplitude of quadrature component of the supply reference currents (I_{spqr}). The instantaneous values are obtained by multiplying the output of this PI controller with the quadrature unit current vectors (w_a, w_b, w_c) derived from unit in-phase current vectors (u_a, u_b, u_c) which are calculated from three-phase sensed terminal voltages. The total reference supply currents are obtained by adding respective in-phase and quadrature components.

PWM based hysteresis current controller is employed over instantaneous reference supply currents and sensed supply currents. If $i_{sa} < (i_{sar}-h_b)$, the upper switch is turned 'OFF' and lower switch is turned 'ON'. If $i_{sa} > (i_{sar}+h_b)$, the upper switch is turned 'ON' and lower switch is turned 'OFF'. In this manner, the switching logic for other two phases is obtained and the controller is able to regulate the currents in a band around the desired reference value.

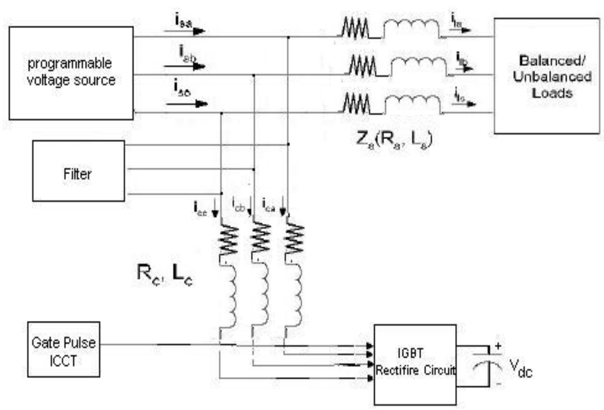

Fig. 1: Block Diagram of DSTATCOM

4. MATHEMATICAL MODELING OF DSTATCOM

3-ϕ reference supply currents are calculated using 3-ϕ supply voltages. These reference supply currents consist of two components, one in-phase and another in quadrature with the supply voltages.

A) In-Phase Components of Reference Supply Current's calculation:-

The amplitude of in-phase component of reference supply currents (I_{spdr}) is kept fixed at a specific value so that DSTATCOM supplies fixed real power. Three-phase in-phase components of the reference supply currents are calculated using the in-phase unit current vectors (u_a, u_b,u_c) derived from 3-ϕ terminal voltage (V_a, V_b, V_c) using the following equations.

$$u_a = V_{ta}/V_{tmn}$$
$$u_b = V_{tb}/V_{tmn}$$
$$u_c = V_{tc}/V_{tmn} \quad (1)$$

The amplitude of the supply voltage (V_{tmn}) is computed as:

$$V_{tmn}= \sqrt{2/3}\ (V^2_{ta} + V^2_{tb}+ V^2_{tc}) \quad (2)$$

The amplitude of in-phase component of reference supply currents is calculated as:

$$I_{sadr}=I_{spdr} * u_a$$
$$I_{sbdr}=I_{spdr} * u_b$$

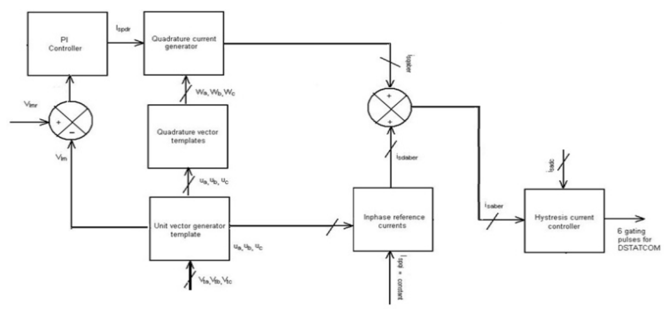

Fig. 2: Control Scheme of DSTATCOM

$$I_{scdr}=I_{spdr} * u_c \quad (3)$$

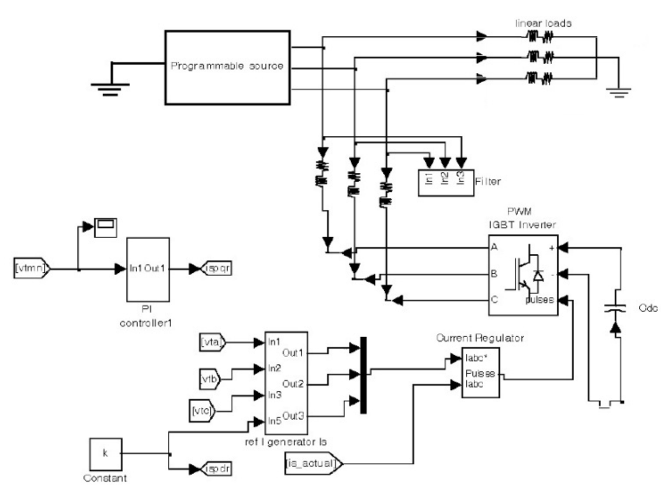

Fig. 3: (a) MIATLAB based model of DSTATCOM system with Linear Load

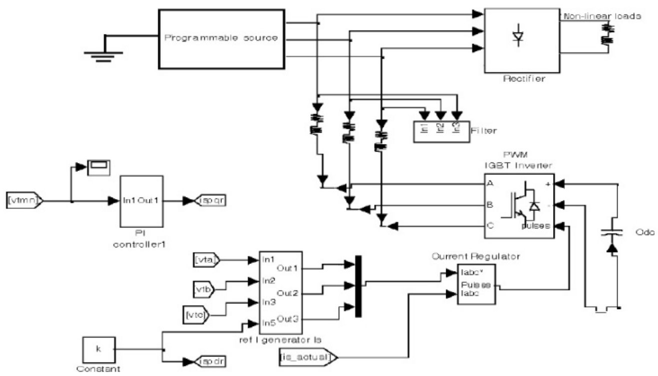

Fig. 3: (b) MIATLAB based model of DSTATCOM system with Non-Linear Load

B) Quadrature Components of Reference Supply Current's Calculattion :-

The amplitude of quadrature component of reference supply currents is computed using a PI controller over the average value of amplitude of supply voltage (V_{tm}) and its reference counterpart (V_{tmr}).

$$I_{spqr}=I_{spqr(n-1)}+K_{pq}\{V_{ae(n)}-V_{ae(n-1)}\}+K_{iq}\,V_{ae(n)} \quad (4)$$

Where $V_{ae(n)}=V_{tmr}-V_{tm(n)}$ denotes the error in V_{tmn} calculated over reference V_{tm} and average value of voltage of V_{tm}. K_{pq} and K_{iq} are the proportional and integral gains of the PI controller.

The quadrature unit current vectors are derived from in-phase unit current vectors as:

$$W_a=(-u_b+u_c)/\sqrt{3}$$
$$W_b=(u_a\sqrt{3}+u_b-u_c)/2\sqrt{3}$$
$$W_c=(-u_a\sqrt{3}+u_b-u_c)/2\sqrt{3} \quad (5)$$

3-ϕ quadrature components of the reference supply currents (i_{saqr}, i_{sbqr}, i_{scqr}) are computed using their amplitude and quadrature unit currents vectors as:

$$i_{saqr}=I_{spdr} * W_a$$
$$i_{sbqr}=I_{spdr} * W_b$$
$$i_{scqr}=I_{spdr} * W_c \quad (6)$$

C) Total Reference Supply Current's Calculation:-

Three phase instantaneous reference supply currents are computed by adding in-phase and quadrature components expressed as:

$$i_{sar}=i_{sadr}+i_{saqr}$$
$$i_{sbr}=i_{sbdr}+i_{sbqr}$$
$$i_{scr}=i_{scdr}+i_{scqr} \quad (7)$$

A hysteresis current controller is employed over the reference and sensed supply currents to generate gating pulse of IGBT's of the DSTATCOM. This gives appropriate gating signals for all the three lags of VSI.

5. MATLAB BASED CIRCUITRY OF DSTATCOM

This section illustrates the model of DSTATCOM along with programmable voltage source. A programmable supply is feeding in to the variety of loads is show in fig 3 (a) and 3 (b). The PI controller is tuned to regulate the ac terminal voltage at the PCC. The power as well as control circuit are molded in Matlab / Simulink and fig 3 (a) (b) shows the Simulink diagram of DSTATCOM and the load of the distribution system. A small capacitor filter is connected to the PCC.

The DSTATCOM configuration has a voltage source inverter molded using universal bridge from PSB toolbox library. It uses IGBTs each shunted by a reverse parallel connected fast switching freewheeling diode. The Linear and Non-Linear loads are connected to the output of the system. The linear load on the system is represented by 3-ϕ resistive-inductive (R-L load) for lagging power factor. Switches are suitably connected for constructing the load either balanced or unbalanced. The Non-linear load connected is represented in the form resistive load connected across a 3-ϕ *diode rectifier. In the DSTATCOM system controller block basically contains* several subsystems like measurement system, reference current generation, ac voltage regulation loop, PI controller and hysteresis current controller. Fig 3(a) shows the Simulink Circuitry of DSTATCOM with Linear Loads and fig 3 (b) shows the Circuitry of DSTATCOM with Non-Linear Loads

Hysteresis controller:-

Hysteresis controller is used independently for each phase and directly generates the switching signals for the switches of the inverter. The error signal is the difference between the reference current and the actual current. If the error current exceeds the upper limit of the Hysteresis band, the upper switch of the inverter arm is turned OFF and the lower switch is turn ON. If the error current crosses the lower limit of the Hysteresis band, the lower switch is turn OFF and the upper switch is turned ON.

6. RESULTS & ANALYSIS OF LINEAR AND NONLINEAR LOAD

LINEAR LOAD RESULT DESCUSSION

Performance characteristics of the DSTATCOM system of Linear load are given in Fig. 5 (a), (b), (c), (d), (e) shows variation of source current (I_s), Triggering pulse, Compensation current (I_c), I_s harmonics spectrum and I_l harmonics spectrum. The required parameters of the system are given in PARAMETER. According to uncompensated line harmonics of Source current (I_s) is 46% and load current (I_l) is 57%. According to IEEE rules harmonics should be less than 5%. In this paper Linear load THD of Source current (I_s) is 0.01% and load current (I_l) is 0.01%.

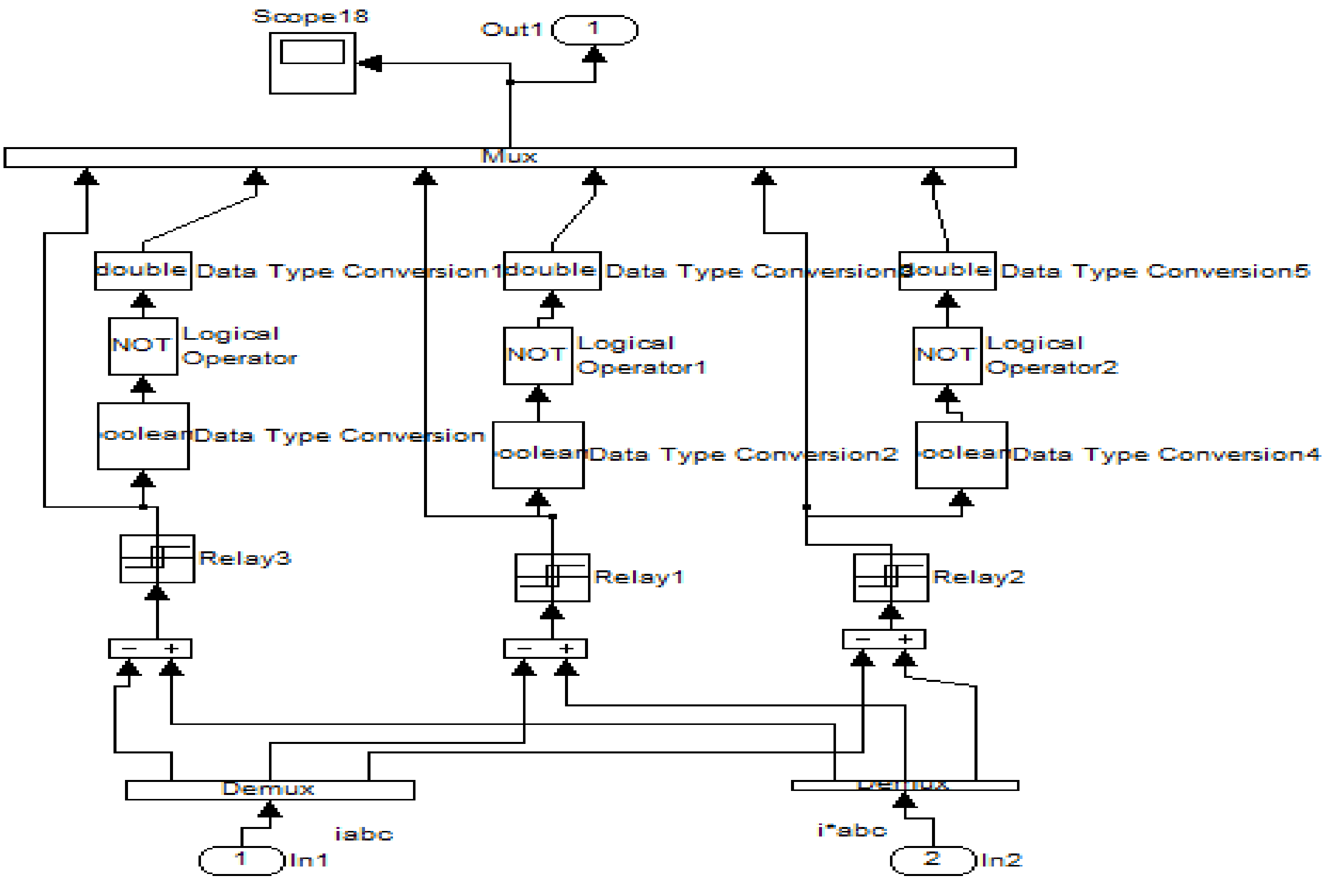

Fig. 4 Simulink of Hysteresis controller

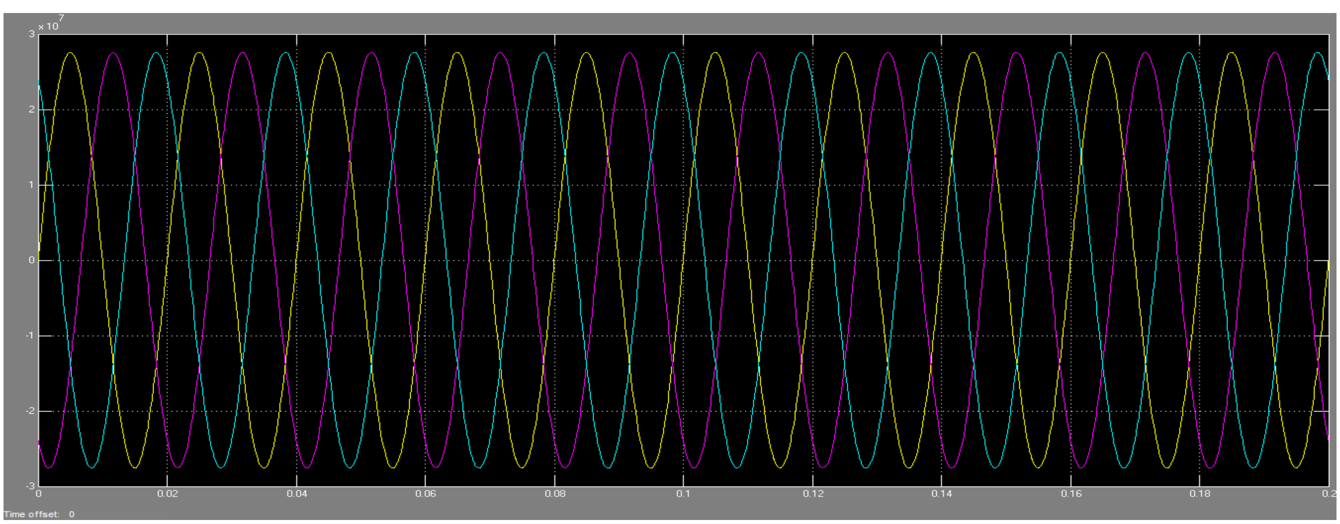

Fig. 5 (a) Source current waveform

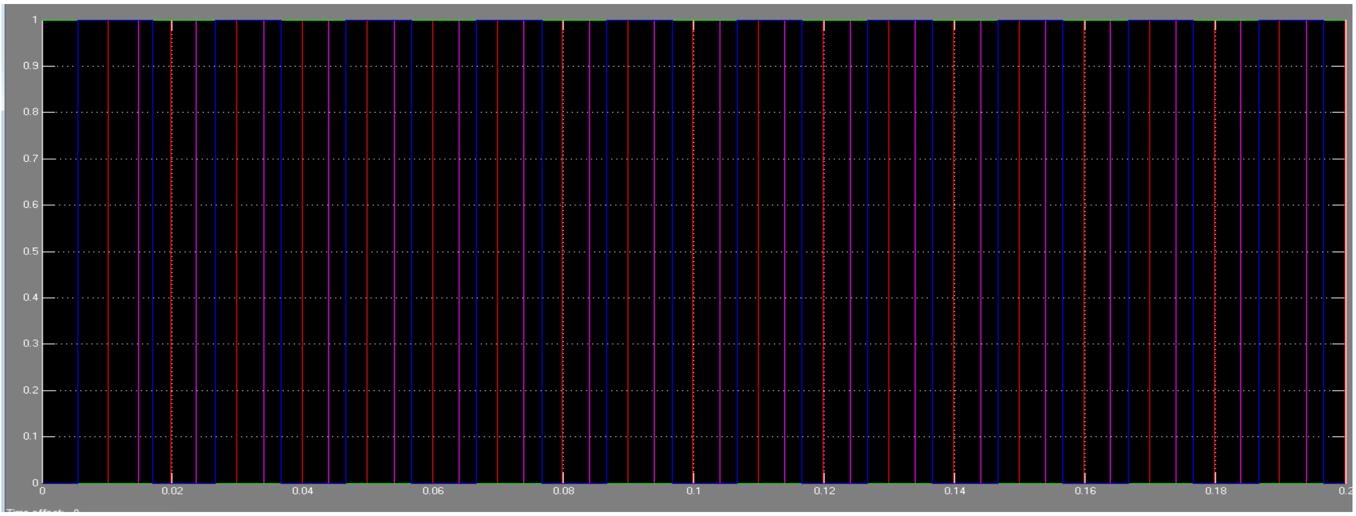

Fig. 5 (b) Triggering pulse waveform

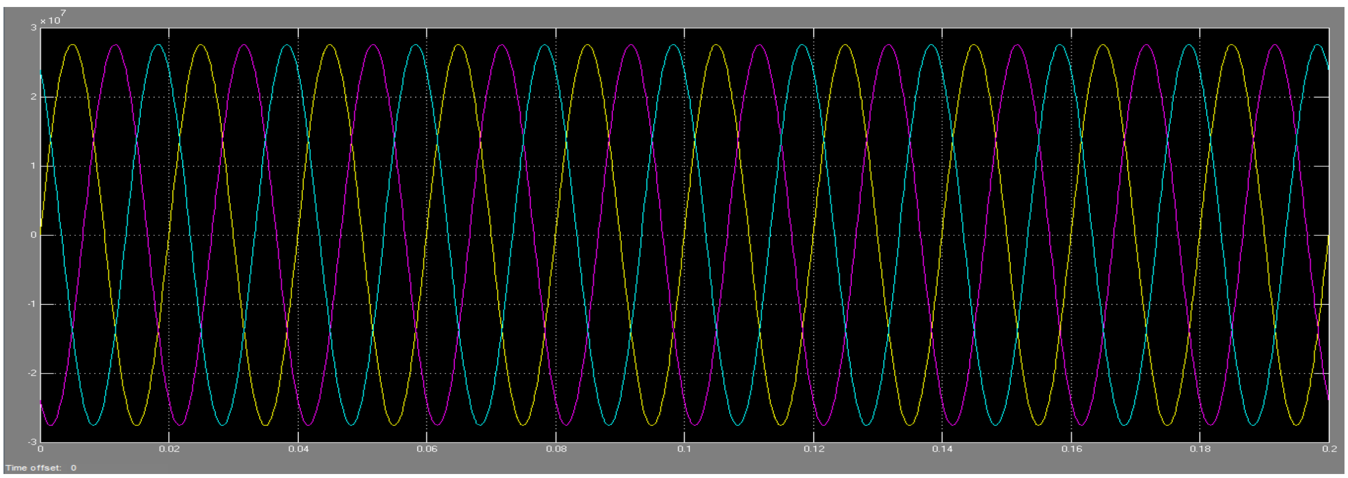

Fig. 5 (c) Compensation current waveform

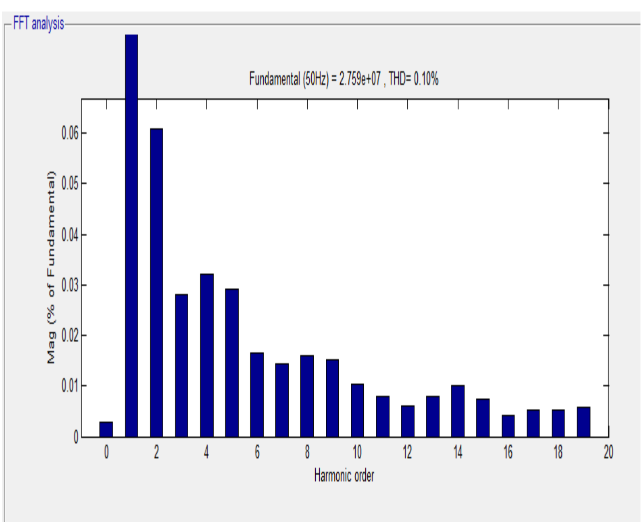

Fig. 5 (d) $I_{:}$ harmonics spectrum

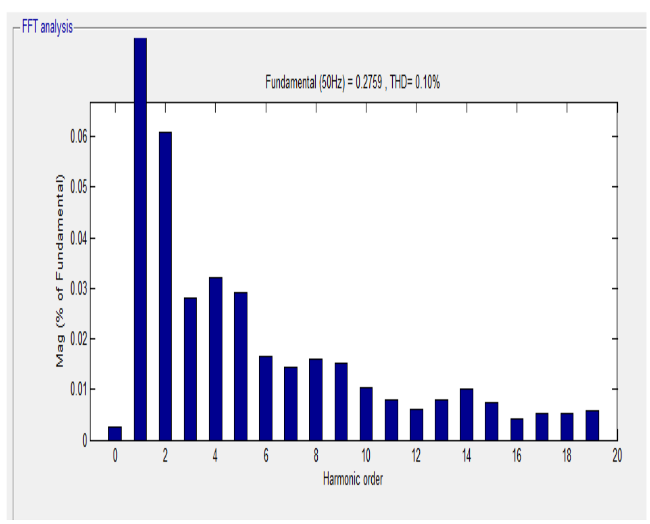

Fig. 5 (e): I_l harmonics spectrum

NONLINEAR LOAD RESULT DESCUSSION

Performance characteristics of the DSTATCOM system of Non-Linear load are given in Fig. 6(a), (b), (c), (d), (e) and (d) shows variation of source current (I_s), Load current (I_l), Gate pulse, I_s harmonics spectrum, I_l harmonics spectrum, I_c harmonics spectrum. The required parameters of the system are given in PARAMETER. In my result analysis nonlinear compensated THD is 0.07%.

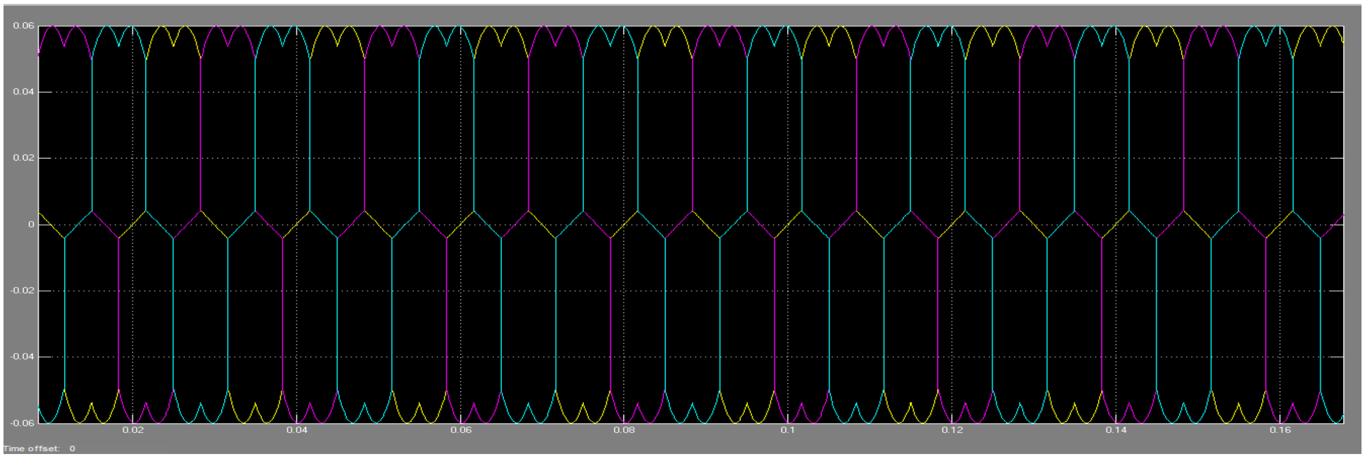

Fig. 6 (a) Source current waveform

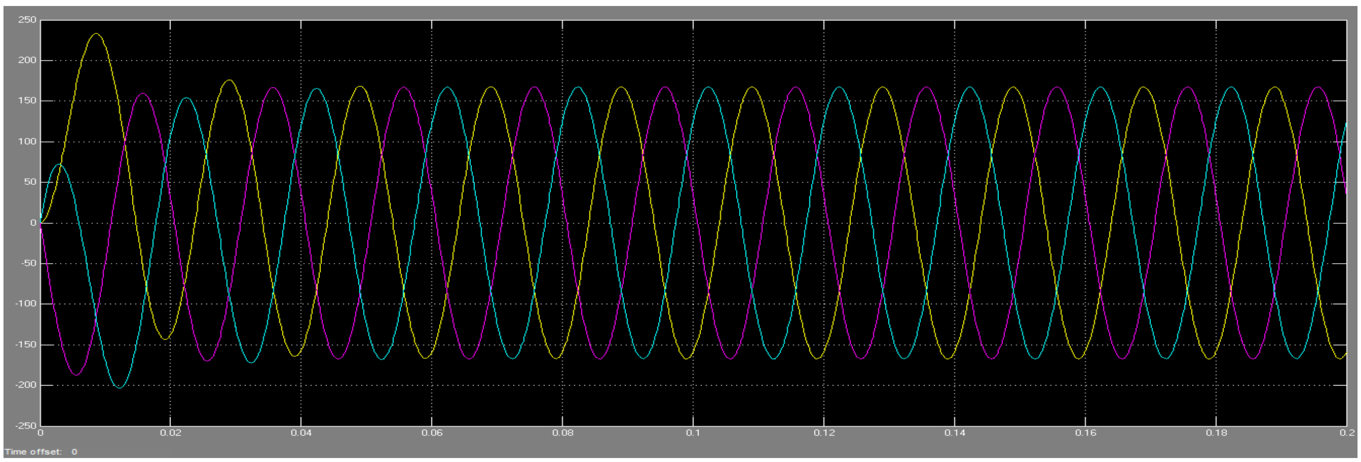

Fig. 6 (b) Load current waveform

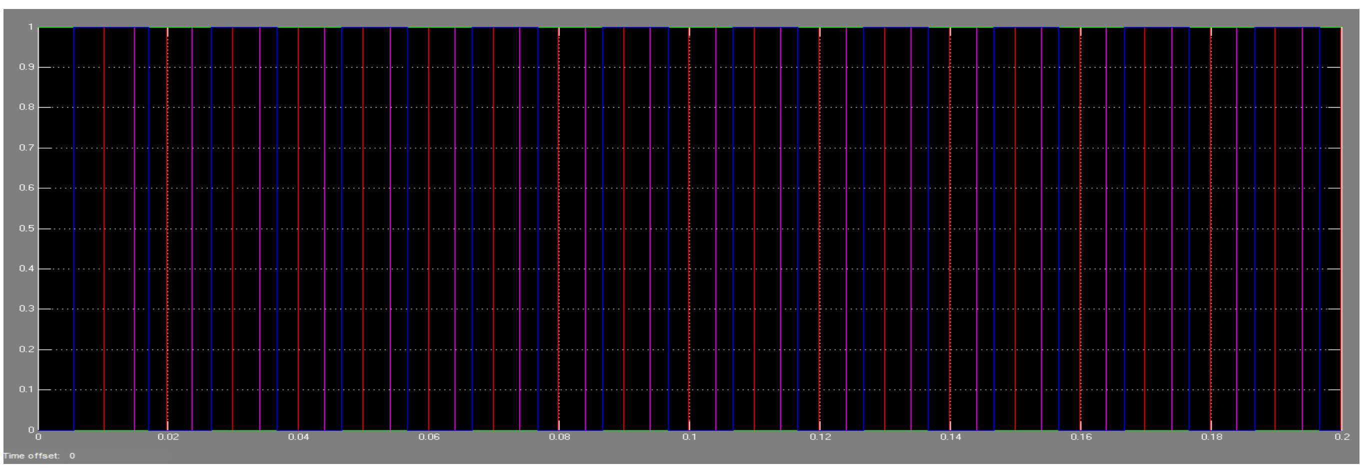

Fig. 6 (c) Gate Pulse waveform

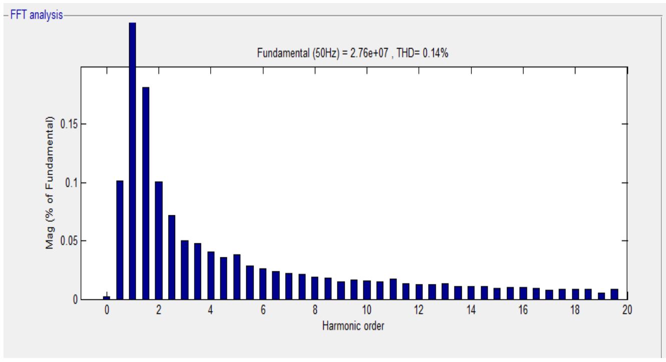

Fig. 6 (d) I_s harmonics spectrum

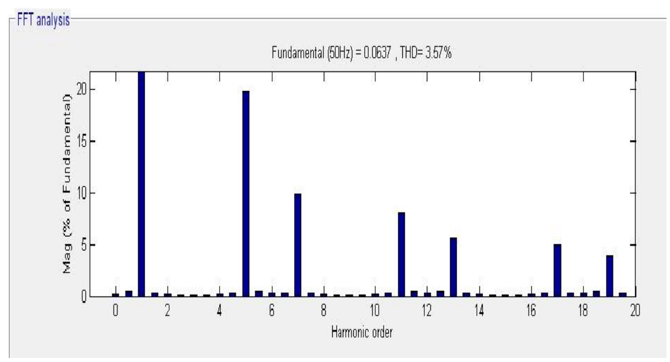

Fig. 6 (e) I_l harmonics spectrum

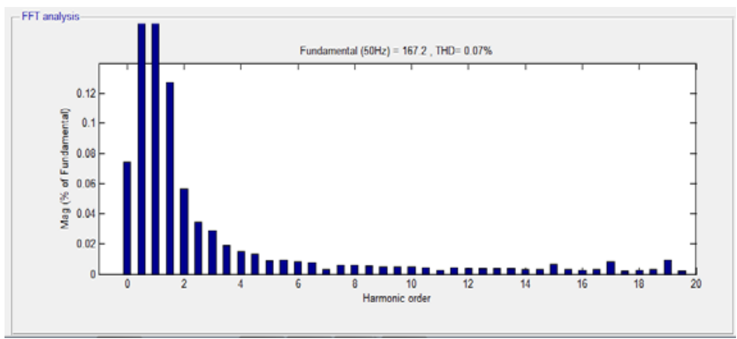

Fig. 6(f) I_c harmonics spectrum

7. CONCLUSION

In recent years, along with the rapid increasing electric power requirement, the reconstruction of India urban and rural power network is more and more urgent. There will be huge demand for reactive power compensation to improve the efficiency and stability of AC transmission systems during transmission upgrade process. This paper introduces STATCOM technologies, and gives a description of its Control theory and to improve power quality with the reduction of Harmonics in the transmission line. when the reactive power will be minimized power factor also be improved as per the IEEE. As one of the second generation FACTS devices, STATCOM should be given more attention for long-term consideration. D-STATCOM is able to reduce harmonics in voltage at PCC and supply currents to less than 5% IEEE 519 standards. BESS reduces harmonics in supply current to a large extent and provides quality power. It is found that DSTATCOM is able to provide more benefits in terms of improved voltage, The results from digital simulation show good dynamic performances of STATCOM in power system voltage regulation.

8. PARAMETERS

L_c= 5mH, R_c=0.1Ω, h_b=0.5A, C_1=5000F, R_l=1000 Ω, P=0.43, I=0.15, D=0.

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